in diameter from 25 to 2,000 mm. the ratio of areas being 1 to 6,000.

It seems very probable that differences found by some observers are due to differences of construction. My own experience in New England and in the West with different kinds of gages, indicates that gages with shallow funnels have larger and more variable errors than do the deeper gages. The greater splashing of the larger drops occurring in summer may explain the deficiency in catch of the 200 cm.[2] gage used by Lindholm at this time of year. In mild climates such as that of England, wet snow adhering to the funnel would cause a more variable, and usually a smaller, catch on the part of the smaller gage.

The ratio V (p. 262) is that of the cylindrical portion of the gage to the area of the funnel (or bottom of the receiver).

PRESENT METHODS OF GLACIER STUDY IN THE SWISS ALPS

J. E. CHURCH, JR.

[Mount Rose Observatory, Reno, Nev., July 10, 1923

Contemporaneous with the later studies in glacier phenomena by Prof. P. Mercanton, of the University of Lausanne, an abstract of whose work appeared in Scientific American Supplement 85:194–5 (Mar. 30, 1918), is the investigation being conducted under the auspices of the Glacier Commission of the Physical Society of Zurich by Prof. A. de Quervain, of the Swiss Central Meteorological Office, assisted by Dr. A. Billwiller. Current reports are published in the Annalen der schweizerischen, meteorologischen Zentralanstalt and in briefer form in the Jahrbuch Ski.

In addition to the traditional measurements of glacier flow, the commission is endeavoring to determine the relation of the source of supply to the forward thrust and retraction of glaciers and to obtain so far as possible a view into the evolution of the glacier snow beneath the surface. The Clariden and Silvretta Glaciers were selected as the subject of study.

As a preliminary, snow stakes were erected at the mountain huts in the catch basin of the individual glaciers to determine the current growth and dimunition in the snow cover, and seasonal snow gages, known as Mougin Totalisators, were installed to determine the total annual precipitation. These consisted of an orifice flanked by a Nipher screen and terminating in a reservoir containing a saline solution in which the falling snow is melted and conserved. A laboratory test of the resulting dilution determines the amount of gathered precipiation. And iron tripod raises the totalizator above the reach of drifting snow.

Although the totalizator is the last word in simplicity, it probably lacks necessary precision, for the air currents in the exposed situations in which the gages are of necessity placed, must often be too strong to be controlled by the screen, and, furthermore, the cold may at times congeal the surface of the liquid content and seriously reduce the capacity of the reservoir by depriving it of its power to change the snow into water. Finally, frost plumes will readily form in cloudy weather upon the orifice and until slowly melted by the returning sun will prevent the entrance of snow. On the other hand, the contents may even be abnormally augmented by "snow smoke" from neighboring peaks unless the totalizator is so situated as to be beyond such influence.

The uncertainty that exists regarding the accuracy of the snowfall measurements is heightened by the fact that glaciers are situated in depressions, well called *glacial collectors*, and are thus the natural recipients of the drifting snow, providing they lie in the lee of the wind. Some glaciers, also, may be abnormal losers of snow, if they face the sun. Consequently, with similar snowfall but dissimilar exposure to the wind and sun, two adjoining glaciers may act quite differently. Furthermore, some basins, as Mercanton has pointed out, may by their topography so restrain glacial flow that excessive accumulation is necessary before forward thrust can occur.[1] Therefore, to determine the factor of accumulation, measurements were begun of the seasonal residue of snow upon the glaciers themselves.

Two points were selected, one at either end of the glacier, and were marked by a steel tube, known as a buoy, which was usually extended 5 to 6 meters each summer to rise above the new snow of the following winter. At first, the accumulation about these buoys was measured in terms of height, a method of considerable accuracy at any time in the season where the snow is wind-blown but particularly so at the close of the season of melting when the snow has attained practically its highest density through crystallization, as shown by the extremes of 49.0 to 61.5 per cent relative density obtained during the first 3 years.

However, to obtain dependable accuracy in connection with buoy measurements and also to obtain a view beneath the surface, a Mount Rose Sampler, made in short sections to facilitate packing up the mountain, was imported into Switzerland just as the Great War was breaking, and by the development of a special ice cutter[2] has been used to penetrate through two seasons' accumulation to the total depth of 5½ meters. To mark the division between the seasonal layers, a sheet of ochre of red or yellow to facilitate identification is spread around each buoy. The tendency of the ochre stain to spread does not militate against its use, for the movement is downward with the percolating water. Consequently, despite a maximum penetration by the ochre of 165 cm., the line between the two seasons' snows is sharply defined.

The immediate result of the measurements was the demonstration that the winter snowfall upon the glacier surface suffers considerably during the brief summer season, for although the water content of the season's snow cover at the end of the major snowfall as on June 17, 1917, was within the reasonable correlation of 20 to 25 per cent of the annual catch in the totalizator, the water content on August 8 was almost 100 per cent divergent. Consquently, the total annual precipitation bears far less relation to glacier growth than the actual residue of snow that remains as the composite result of winter snows and summer melting; although it is quite possible that a portion of the percolating waters may combine with the glacial snows below.

The second result, brought to light by the divergence between the accumulation indicated by the buoy and

[1] The analysis of these three factors of accumulation, dissipation, and topography would find a harvest time of opportunity in a season such as 1918–19. In this year of heavy snowfall, as noted by Mercanton, of 100 glaciers, 69 were growing, 4 were stationary, and 27 were diminishing. It will be of great interest to obtain the statistics for 1920–21, when the snowfall was light and the succeeding summer unusually warm. Of course, large glaciers, or rather glaciers with large collectors, should show less seasonal variation and might even continue to grow over one or even more deficient seasons. As Professor Mercanton remarks in this connection, "the large snow glaciers have without exception manifested a tendency to grow."

[2] Owing to the tendency of the ice to melt under pressure and friction of the cutter and then to refreeze immediately above it, leaving it imprisoned like a fish in ice, a set of teeth was cut on its bulbous upper side in order that by reversing the direction of rotation of the sampler, the cutter could recut its way to the surface.

that actually measured by the sampler, was the discovery that the lower strata, at least to a limited distance beneath the surface, are undergoing diminution in depth, and the penetration of two seasons' layers in 1917 proved that this diminution was due to loss of water content through melting with but little increase in relative density and, consequently, with little change in crystallization. The loss reached 75 cm. water content in a total of 200 cm., a considerable amount in relation to the seasonal residue, but slight unless frequently repeated, if compared with the cross-section of the glacier. If this melting occurred beneath a new layer of snow, which was 330 cm. thick, the phenomenon has great significance, for it indicates hidden losses occuring in the depth of the glacier. However, it is probable that this melting occurred immediately after the original measurement was made, for August 16 seems too early a date for continuous freezing. At least, in 1917 a loss of 59 cm. or more occurred in the 1916–17 stratum after the August measurement was made. It is, possible, however, that percolating waters from the surface stratum directly above cause this melting as they filter through the fissures below, a normal procedure in snows where the temperature does not remain continuously below 32° F. Only late measurement after the season of melting is over will eliminate the uncertainty regarding the actual water content of a season's residual snow. When once the winter has set in, it seems highly probable that the residual snow of the preceding season is protected against further loss unless its surface is nearly or quite exposed.

Early autumn snows are no obstacle to late measurements, for they can be easily identified by their crystallization and eliminated. The preferred method is to make an early survey before any melting of the winter snow cover has occurred and a late survey, as apparently is now being done, after the melting has ceased. Thus the actual seasonal catch of snow by the glacier can be compared with the catch in the totalisator and both catch and summer's residue accurately determined. Only in this way can the three studies of the Zurich Glacier Commission, viz, precipitation, stream-flow, and glacier science be advanced.

Regarding the internal growth of glaciers, it is probable that the residual snow stratum of any season undergoes slow pressure by succeeding strata, until it finally attains the density and crystallization of glacial ice. Such process must naturally be slow, for the density before the heavier pressure begins has usually already reached the high percentage of 60 to 62.5, or 10 per cent higher than normally found in the Sierra Nevada. Indeed, on the Rhone Glacier in August, 1918, three strata of snow of a combined depth of 317 cm. were penetrated that showed the progressive density of 52.4, 59.0, and 74.3 per cent, respectively, but unfortunately through inability to find the ochre stains it is uncertain whether these three strata represent one or more seasons' snows. However, since the next stratum could not be penetrated despite several efforts to do so, it is safer to consider the three strata as belonging to one season. To settle the question of glacial growth, the annual measurements should be made late in the autumn and the development of the crystallization in the strata downward observed. This might be accomplished by pits or by shallow drifts into the wall of a crevasse, if the latter operation is at all feasible. However, since a gap of only 17.4 per cent still remains between the 74.3 per cent found near the surface of the Rhone Glacier and 91.7 per cent, the density of solid ice, the evolution of solidified snow to coarse glacial ice should be a matter of a few meters depth or a slight increase in pressure, if indeed, temperature itself does not effect the complete evolution unaided by pressure.

The determination of the details of the phenomenon of rapid thrust and retraction must await the accumulation of several years of measurements—of years abnormally heavy and those abnormally light, and each type should preferably be bunched. Furthermore, the heavy winters should be followed by cold summers and the light winters by warm summers to accentuate the extremes.

Fortunately, precipitation is usually uniform within 10 to 20 per cent for distances of 100 to 200 miles along a mountain range, as shown by snow surveys and studies of stream flow in the Sierra Nevada. Consequently, one precipation station or snow survey course, if carefully located beyond possibility of being affected by wind, will serve a considerable area. However, the tendency of each glacial basin to be affected by wind and sun must be determined in the case of each in order to apply the seasonal percentage of precipitation correctly. Basins acting out of unison with their neighbors should be studied individually.

Although glacial ice responds more slowly than water to pressure, there seems to be no reason to expect any fundamental difference from the general law of hydrostatics. Increased head should result in increased rate of flow and vice versa and the terminus of the glacial tongue should be determined by the component of glacial accretion and disintegration. In other words, it should depend upon the interplay of precipitation and temperature, modified, of course, by the plasticity of the glacial ice.

The tendency of glaciers to flow "by fits and starts," or, changing the figure, to explode through excessive tension, seems to be a question of attaining momentum, while the tendency of the "intumescence" to advance more rapidly than the glacier itself could well be the counterpart of streams in flood, whose main current is paralleled by reverse currents near the shore.

Increase in velocity with increase in temperature, though reaching 100 per cent as between the widely divergent temperature of winter and summer, is relatively small as between the normal and supernormal temperature of either, and is a distinctly minor phenomenon as compared with velocity due to pressure. For example, the Mer de Glace in Switzerland moves about one-half foot per day in the center in winter and one foot per day in the summer whereas the glaciers in Greenland flowing from the deep ice cap "usually move about 20 feet per day, and may progress as fast as 50 to 60 feet daily." [3] Yet the mean annual temperature of Switzerland in 35° F. higher than in Greenland.[4]

For those who seek correlations, the appended table on Klariden Glacier will prove of interest. It indicates the general plan and pathetic paucity of assembled data. However, resolute hearts and sturdy bodies will gradually fill the gaps in glacial knowledge. Even as early as 1920, the auspicious beginning caused Doctor Billwiller to remark: "Our glacier commission is growing in years; marked not by the number of our annual reports, nor the pains it has cost nor the sweat, and the weight of the pack, but by the satisfaction with which our insight into the mutual working of glacier growth and melting is deepening year by year."

[3] Excerpted from Rapports au Conseil Federal Suisse by Nigretti & Zambra in Meteorological and other Facts and Data, 1920.

[4] Mean annual temperature of Switzerland approx. 50-55° F.; of Upernavik, Greenland approx. 15-20° F. (Buchan, Atlas of Meteorology).

TABLE 1.—*Glacier studies on Klariden Glacier, Switzerland*

Period	Seasonal snowfall: Totalisator (Geissbutzistock), cm. water annual, Aug. to Aug.	Seasonal snowfall: Upper buoy (maximum snow depth in May) cm. snow	Character of year: Winter and spring	Character of year: Summer	Seasonal residue of snow or glacier growth (sampler measure Aug. or Sept.), cm. water: Upper buoy 2,900 m. elevation	Seasonal residue of snow or glacier growth (sampler measure Aug. or Sept.), cm. water: Lower buoy 2,708 m. elevation	Rise or fall of Niveau (m.)	Flow of glacier as measured at buoys (m.)
1914-15 (Nov.-Aug.)						125 [1]		
1915-16 (Aug.-Aug.)	401				Approximately 258 [2].	Approximately 192 [4].		
1916-17 (Aug.-Aug.)	344	430	Heavy precipitation.	Warm	Approximately 222 [3].	0	Sunk	
1917-18 (Aug.-Sept.)	363	550 or more	Maximum snow depth in July.	Fair weather	238	120	Somewhat risen.	Upper buoy 18 m. (1 yr.) Lower buoy 11.9 m. (2 yrs.)
1918-19 (Sept.-Sept.)	380	550 or more (at Hut 380 in May).	Abnormally heavy snowfall.	Warm Aug.-Sept.	338 or more	242		East end 29 m. (1 yr.)
1919-20 (Sept.-Sept.)	380				336 [5]	84		Buoy covered by new snow in August before measurement could be made.
1920-21 (Sept.-Sept.)	210	205 (Mar. 31) 265 (July	Abnormally light snowfall.	Abnormally warm.	0 (Aug. 3) [6] -39 (Sept. 15)	350 (Aug. 3) [6] 500 (Sept. 15)		Buoy buried in 1920 reappeared. By it movement 2 years (1919-21) 32 m. S. E. By new buoy 1 year (1920-21) 13 m. S. E.

[1] Estimated on basis of 60 per cent of depth of 209 cm.
[2] Estimated on basis of 60 per cent of depth of 430 cm.
[3] Estimated on basis of 60 per cent of depth of 370 cm.
[4] Estimated on basis of 60 per cent of depth of 320 cm.
[5] Buoy lost. Estimated on basis of 60 per cent of depth of 209 cm.
[6] Season's snow entirely melted, so sampler could not be used. Losses of previous season's residue indicated by minus quantities, is on basis of 60 per cent of depth measured, though on account of pressure and weathering, it may be somewhat more.

WIND DIRECTIONS AND VELOCITIES, NASHVILLE, TENN.

551.55 (768)

By ROSCOE NUNN, Meteorologist

[Weather Bureau, Nashville, Tenn., June 5, 1924]

WIND DIRECTIONS

The writer has often wondered as to what may be usually understood by the expression, "prevailing wind direction." It is perfectly clear to the meteorologists, but probably not at all so to the technically uniformed. The ordinary statement, "prevailing wind," means the wind that was registered or observed most often during a given period—the one direction, of the eight principal points of the compass, from which the wind was most often blowing.

If the prevailing wind for any month should be published as "north," that would mean that no other direction, of the eight points considered, was registered as often as north; but it would not mean that the wind was from the north most of the time, nor necessarily for even any high percentage of the time. It is conceivable that the wind might blow from each direction the same length of time during a day or a month; then each of the eight directions would have a percentage of 12.5; but if north should have 13 per cent and no other direction more than 12.5, then north would be the "prevailing wind," although, as a matter of fact, the other seven directions might be practically as highly represented as north.

As usually published, "prevailing wind" data are inexplicit. In order really to understand the characteristics of the wind at any station, the percentages of time for each direction should be known. To furnish such information is the object of the first part of this paper,

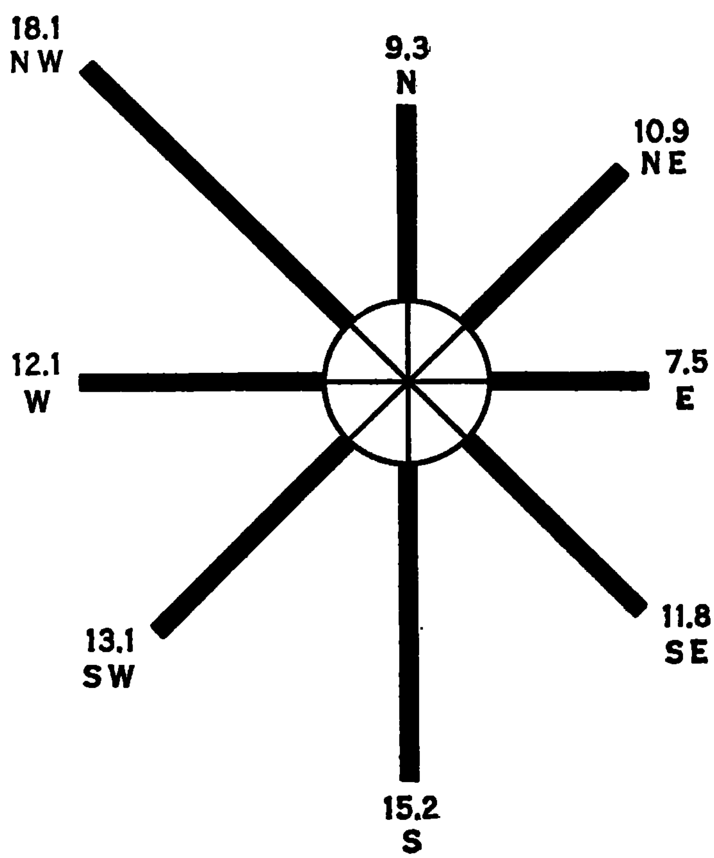

FIG. 1.—Annual average percentage of time the wind blows from the eight principal points of the compass at Nashville, Tenn.